Wide-Field Imaging Interferometry

Enabling General Astrophysics Observations with TPF-I/Darwin

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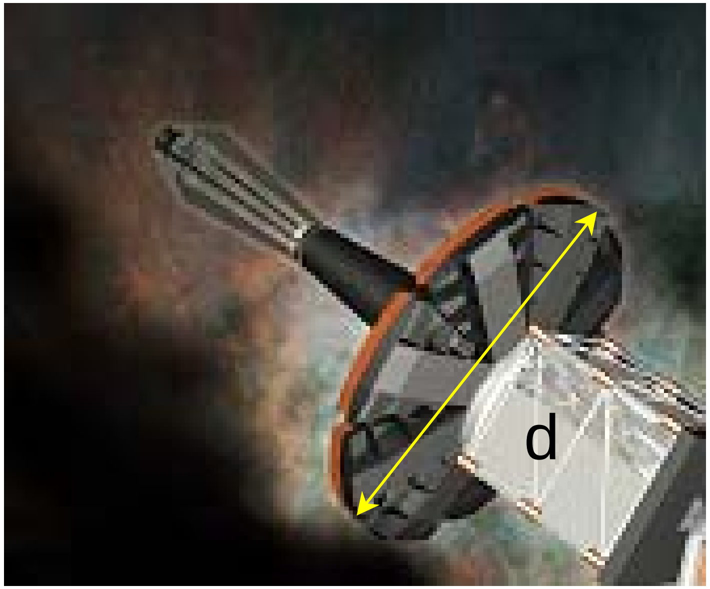
[1] At NASA's Goddard Space Flight Center unless noted otherwise

The wide-field imaging problem



- FOV in a traditional single-detector stellar interferometer is the primary beam of the individual telescope apertures, ~ $1.2\lambda / d$
- This is much smaller than the FOV typically desired

The wide-field imaging problem

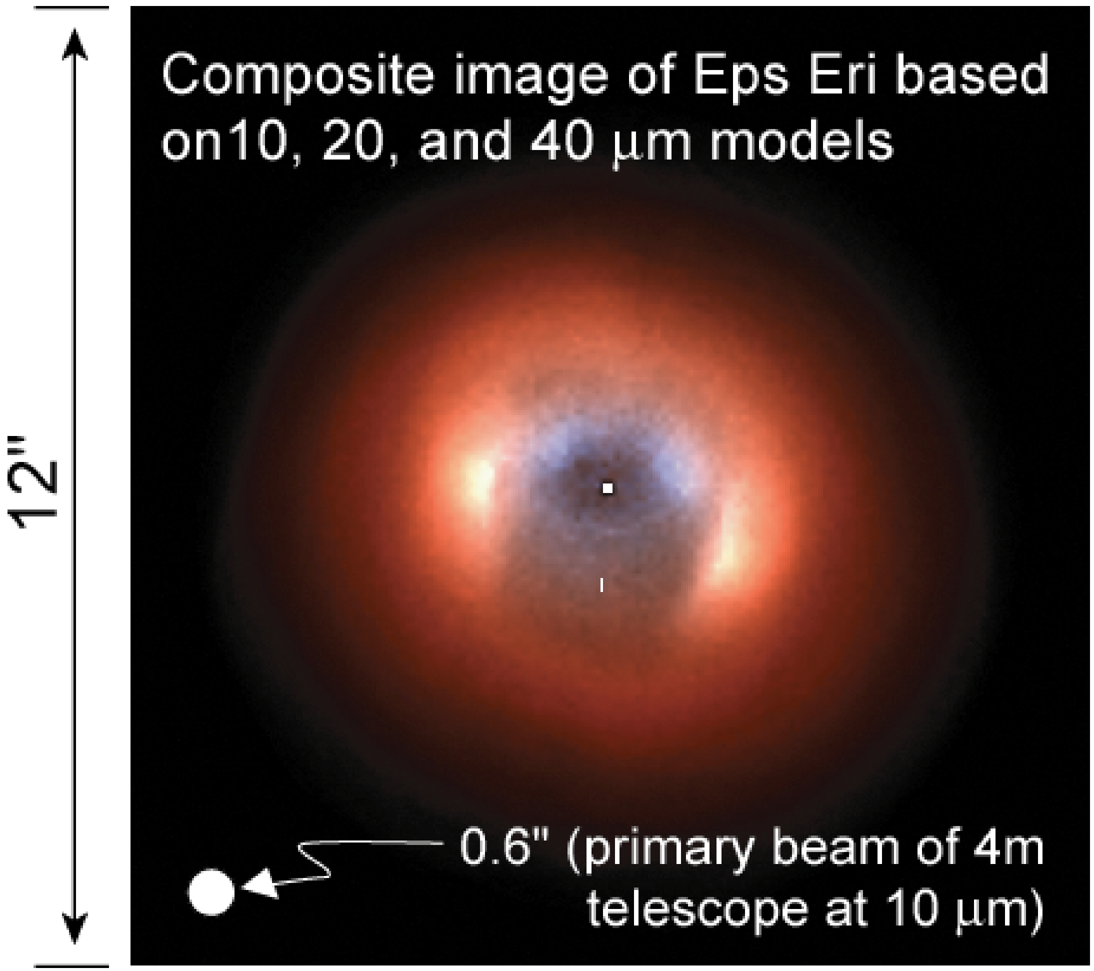
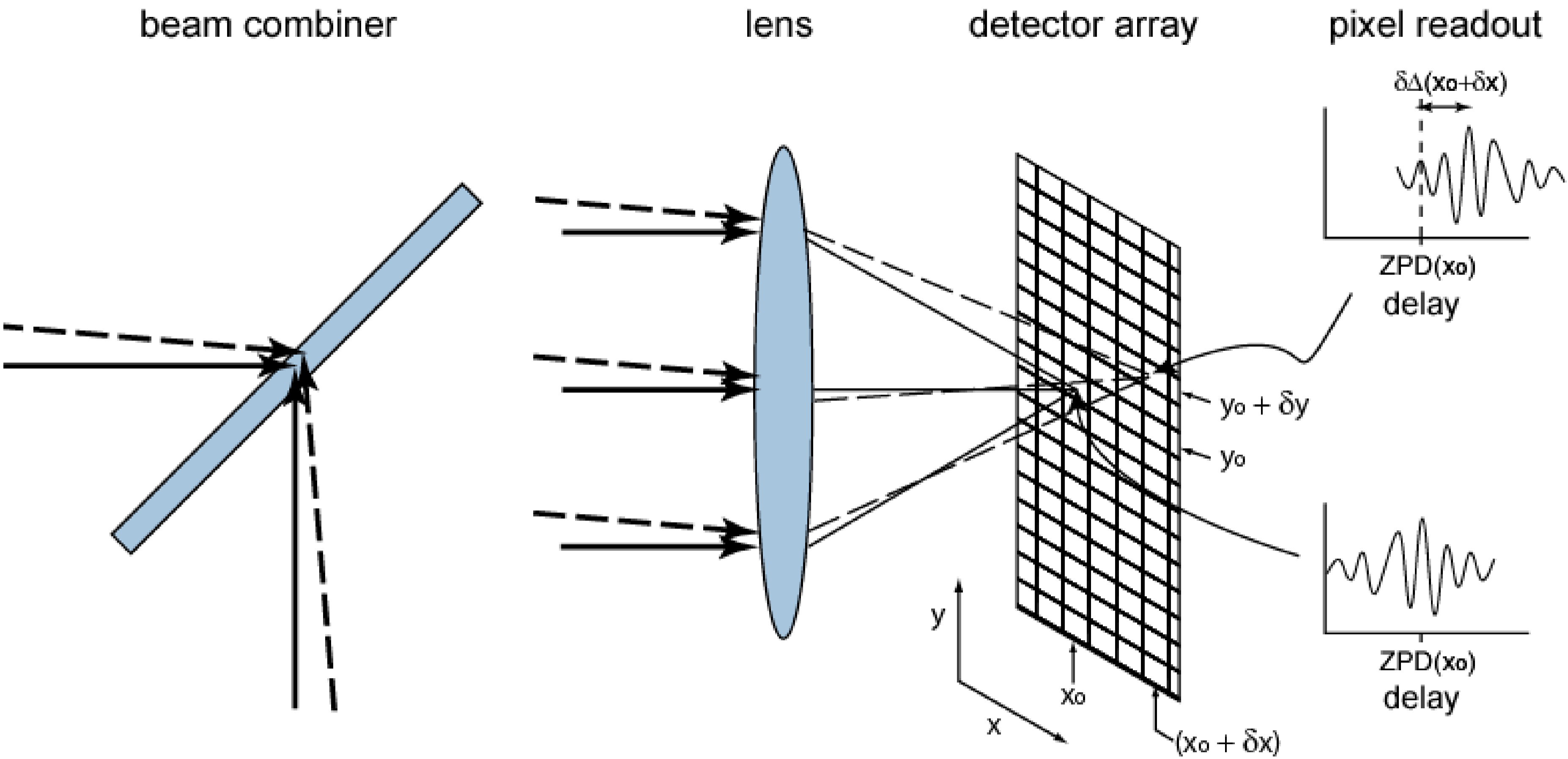


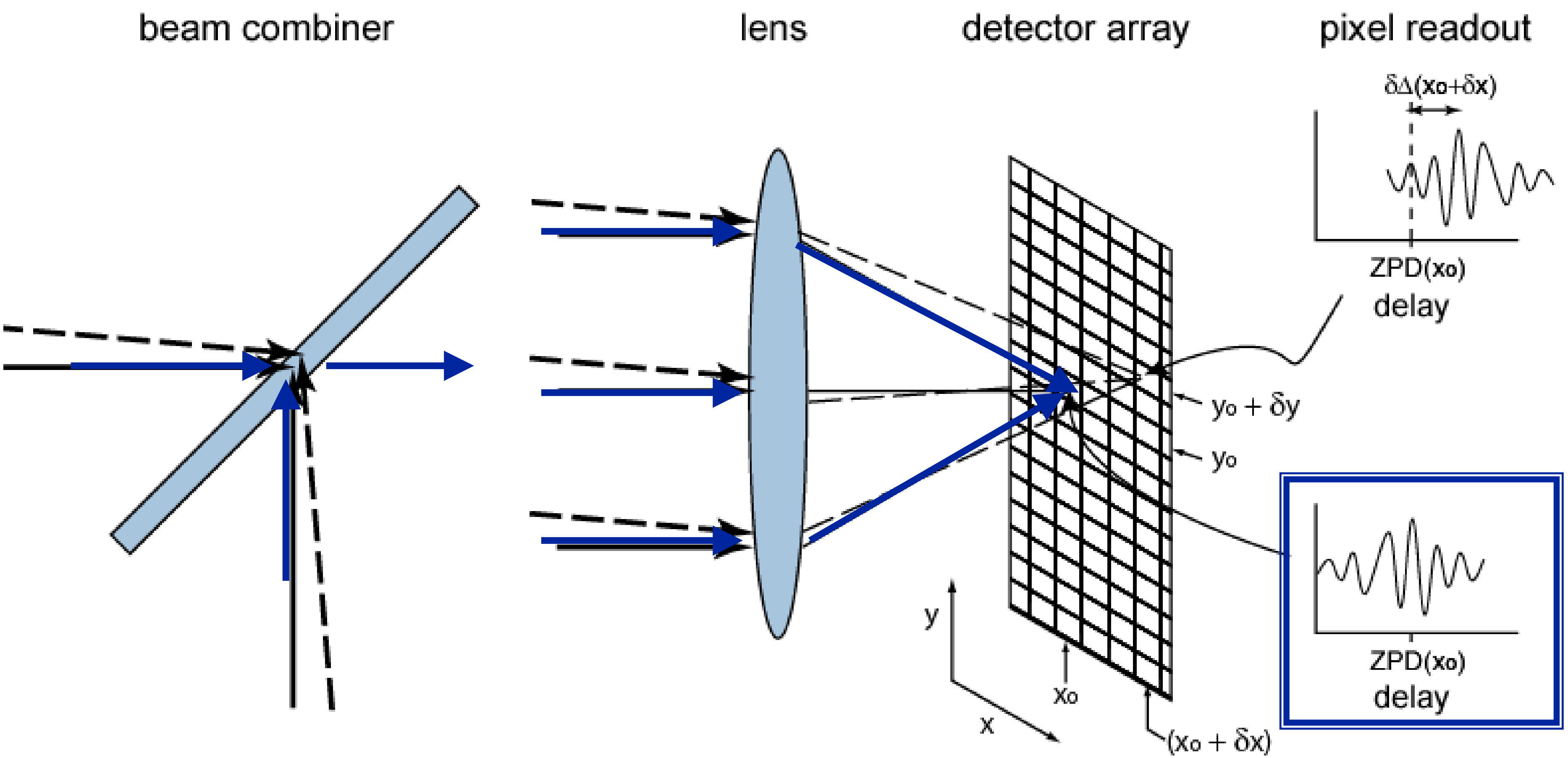
Image courtesy of Moran & Kuchner

- FOV in a traditional single-detector stellar interferometer is the primary beam of the individual telescope apertures, ~ 1.2λ / d
- This is much smaller than the FOV typically desired
- A FOV about 10 - 20x larger would be very nice for debris disk imaging, even larger for other problems

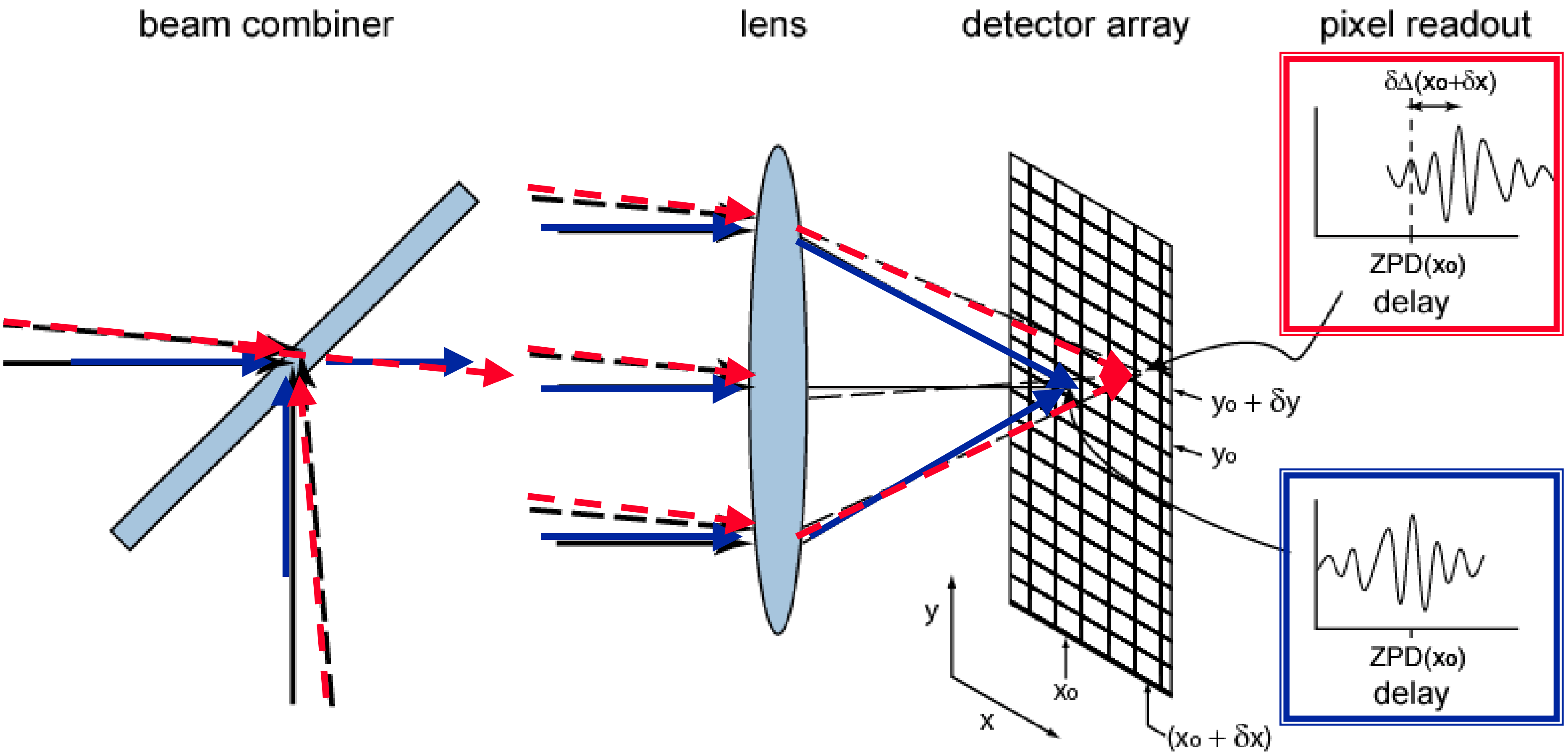
A possible solution



A possible solution



A possible solution



$$\theta_{FOV} \approx 31 \text{ arcsec } (N_{pix}/100)\ (\lambda/10\ \mu m)\ (d\ /4\ m)^{-1}$$

Project goals and approach

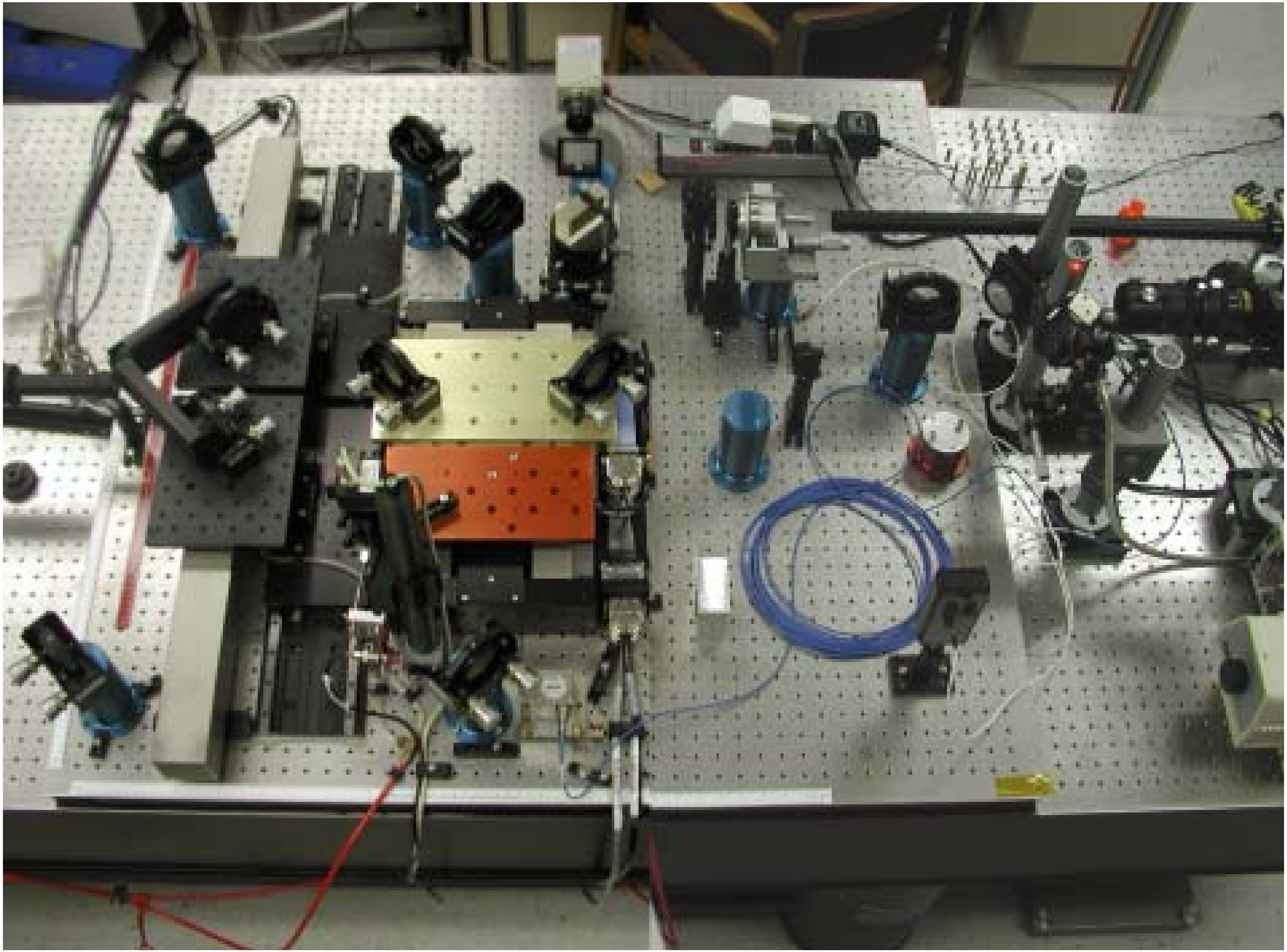
We are developing a technique for wide-field imaging suited to space-based far-IR/sub-millimeter interferometry, and potentially applicable to TPF.

Our goal is to demonstrate that an optical/IR Michelson interferometer equipped with a multi-pixel detector array can image a complex, extended scene over a wide field of view (i.e., $\theta_{FOV} >> \lambda/d$)

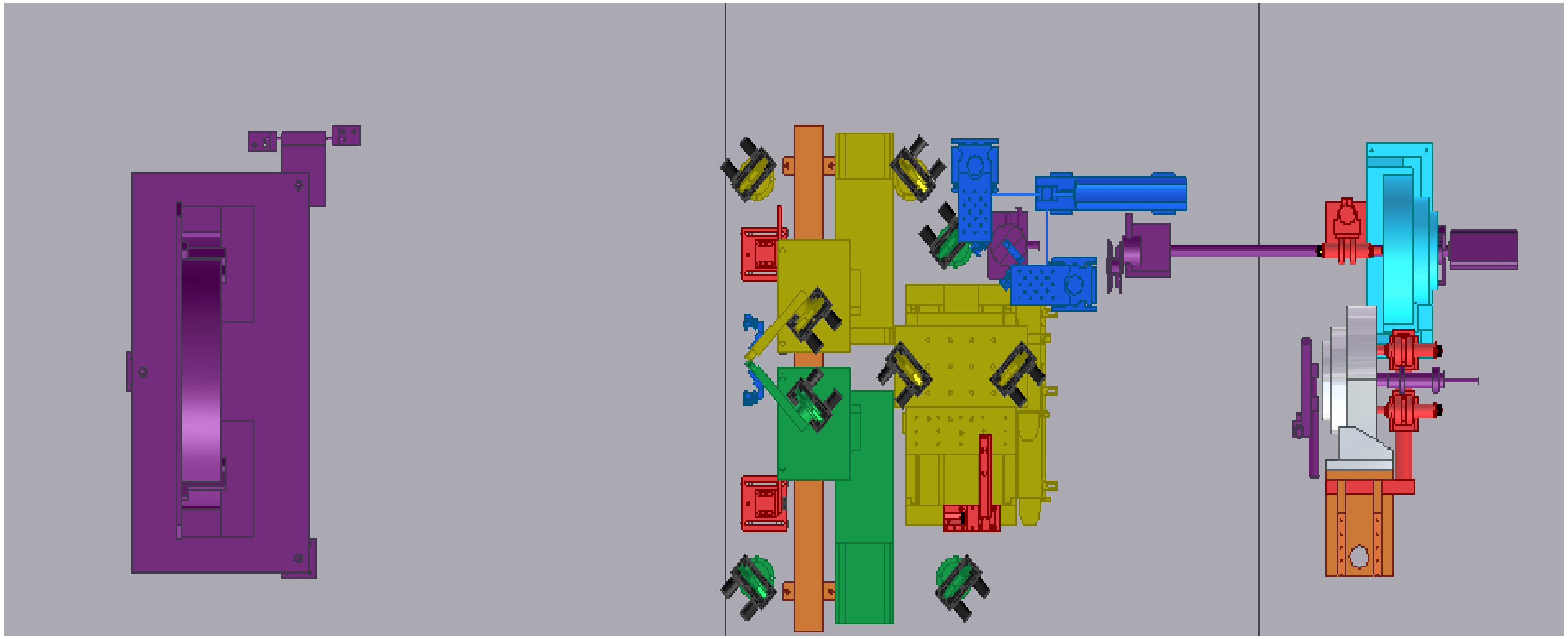
Approach

- Build a "double Fourier" Michelson interferometer
- Obtain representative data
- Develop new spatial-spectral synthesis algorithms

Wide-field Imaging Interferometry Testbed (WIIT)



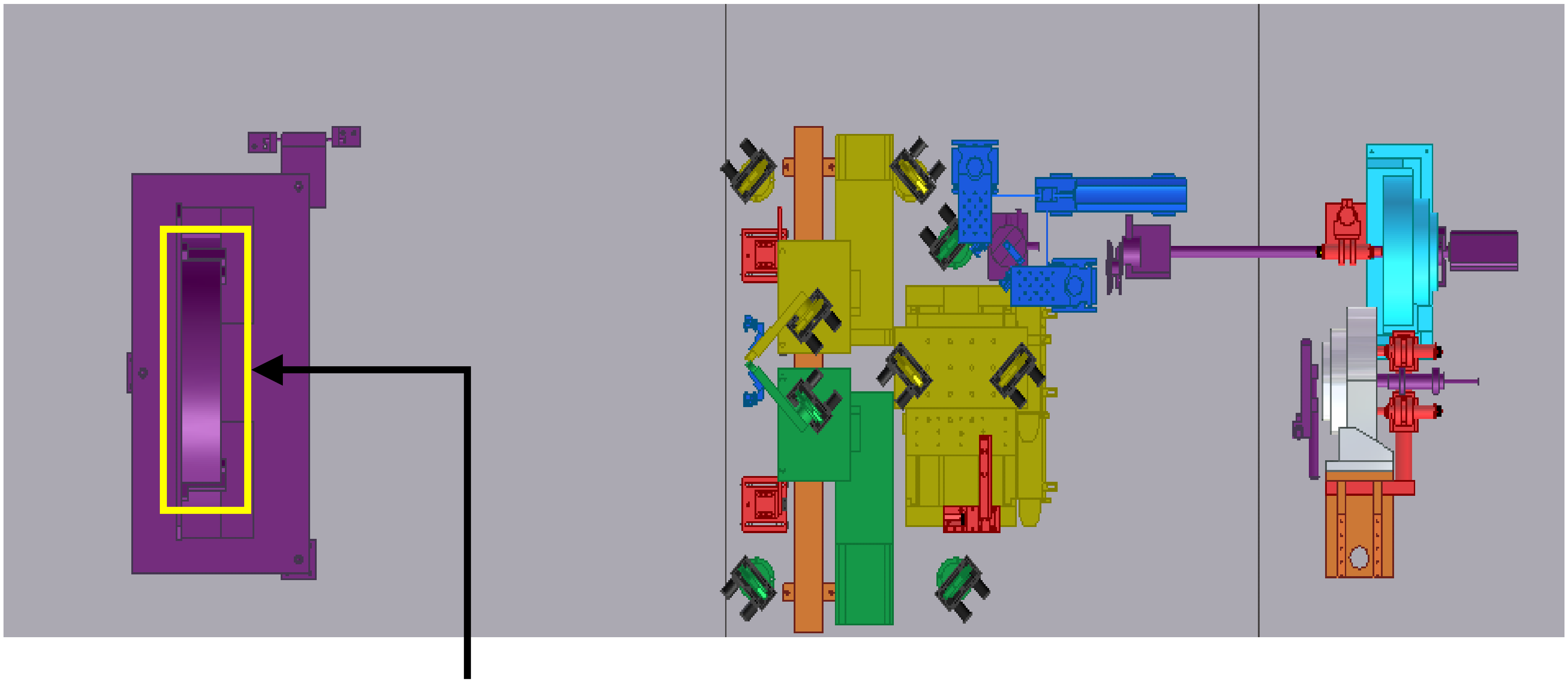
WIIT Schematic - Plan View



WIIT Schematic - Plan View

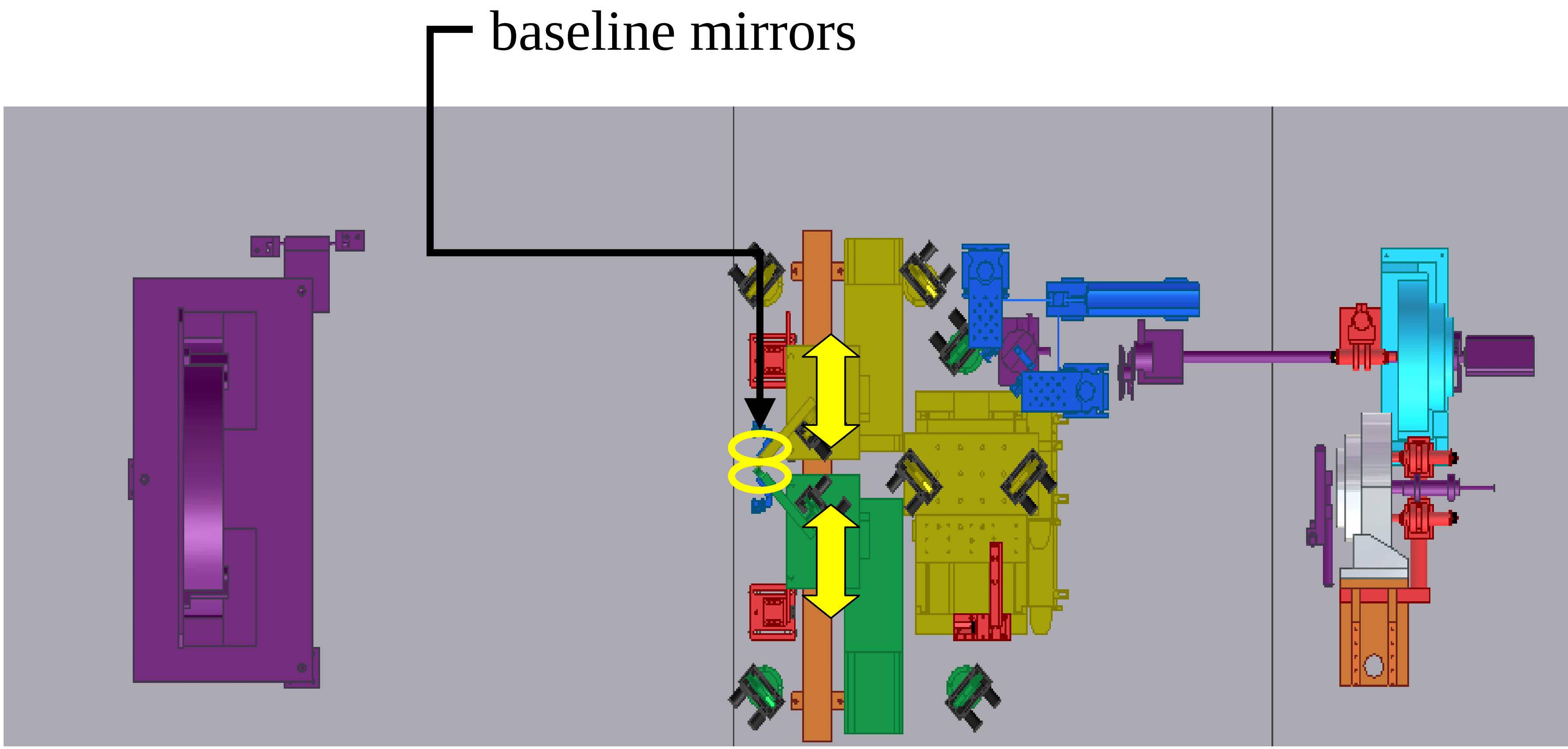
extended broad band
scene

WIIT Schematic - Plan View



parabolic collimating mirror

WIIT Schematic - Plan View



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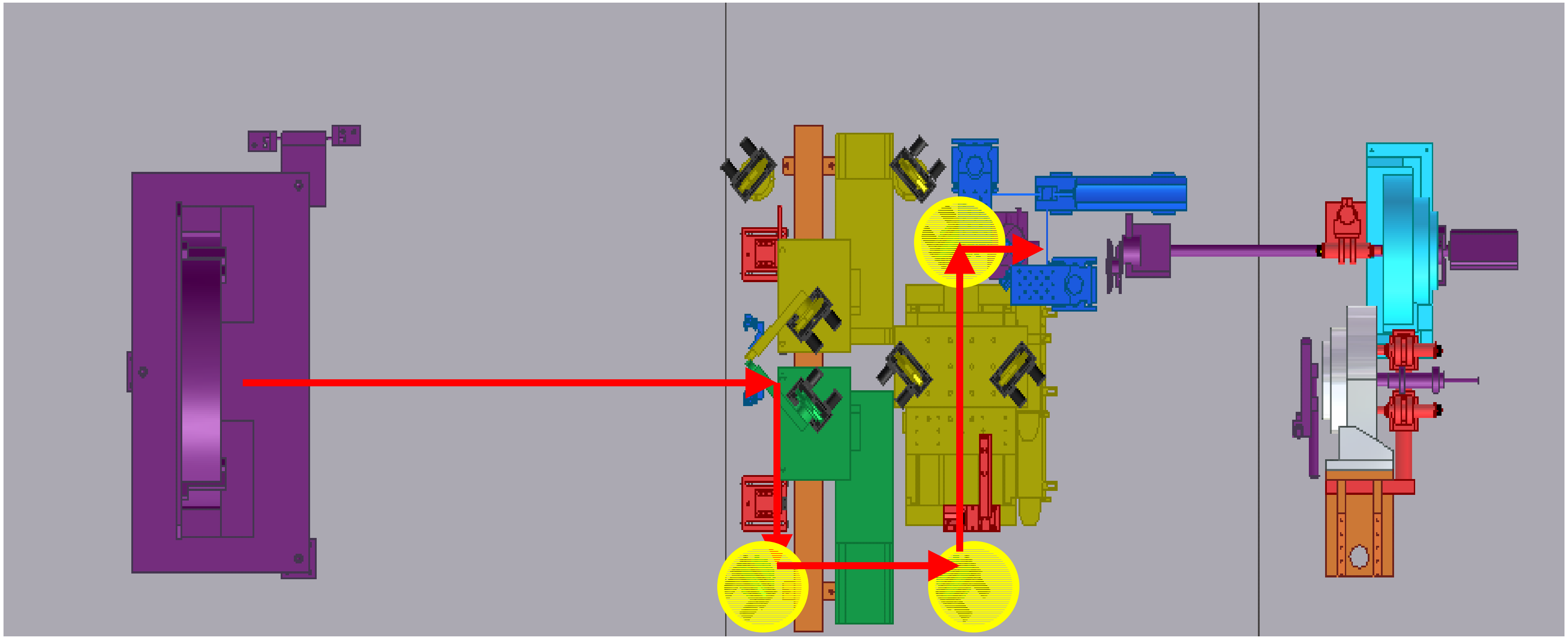
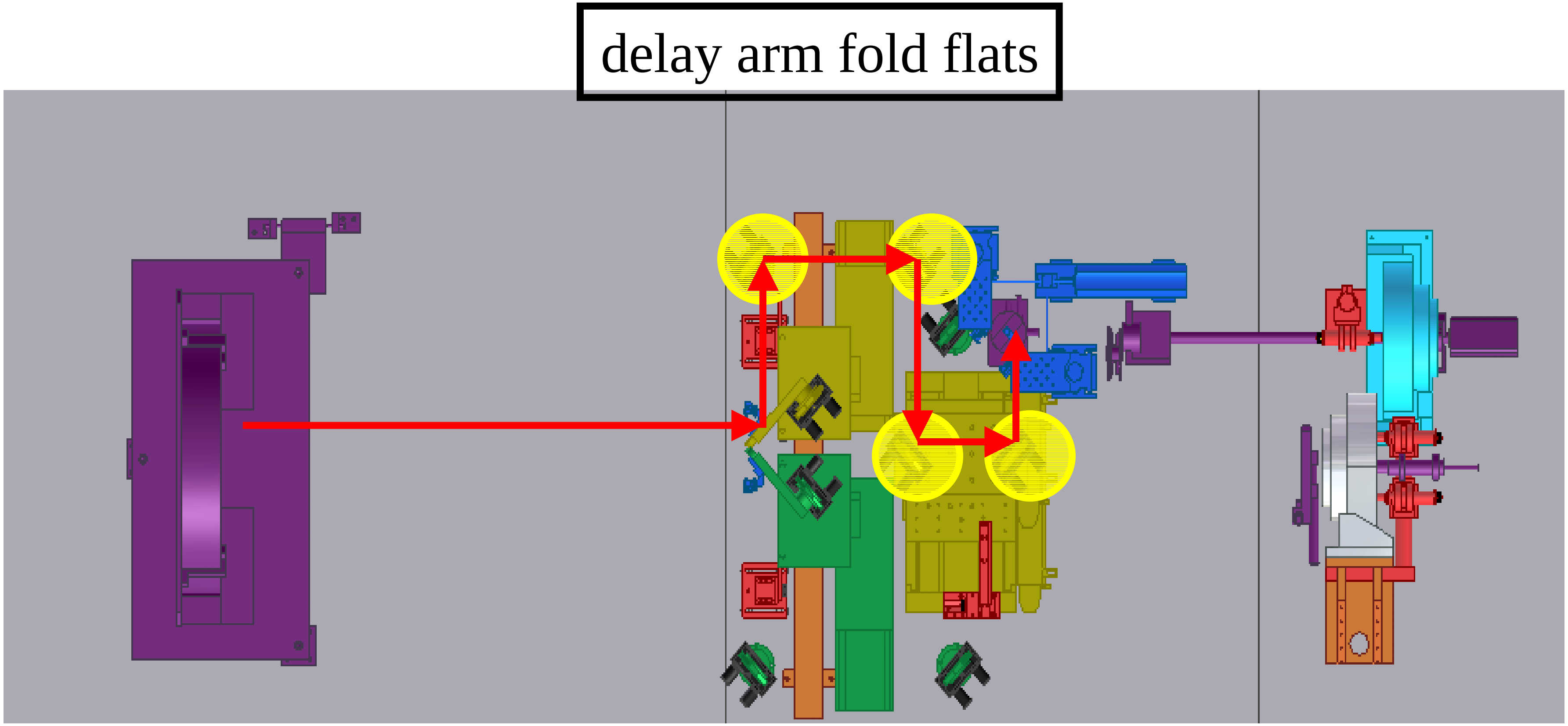


fixed arm fold flats

WIIT Schematic - Plan View



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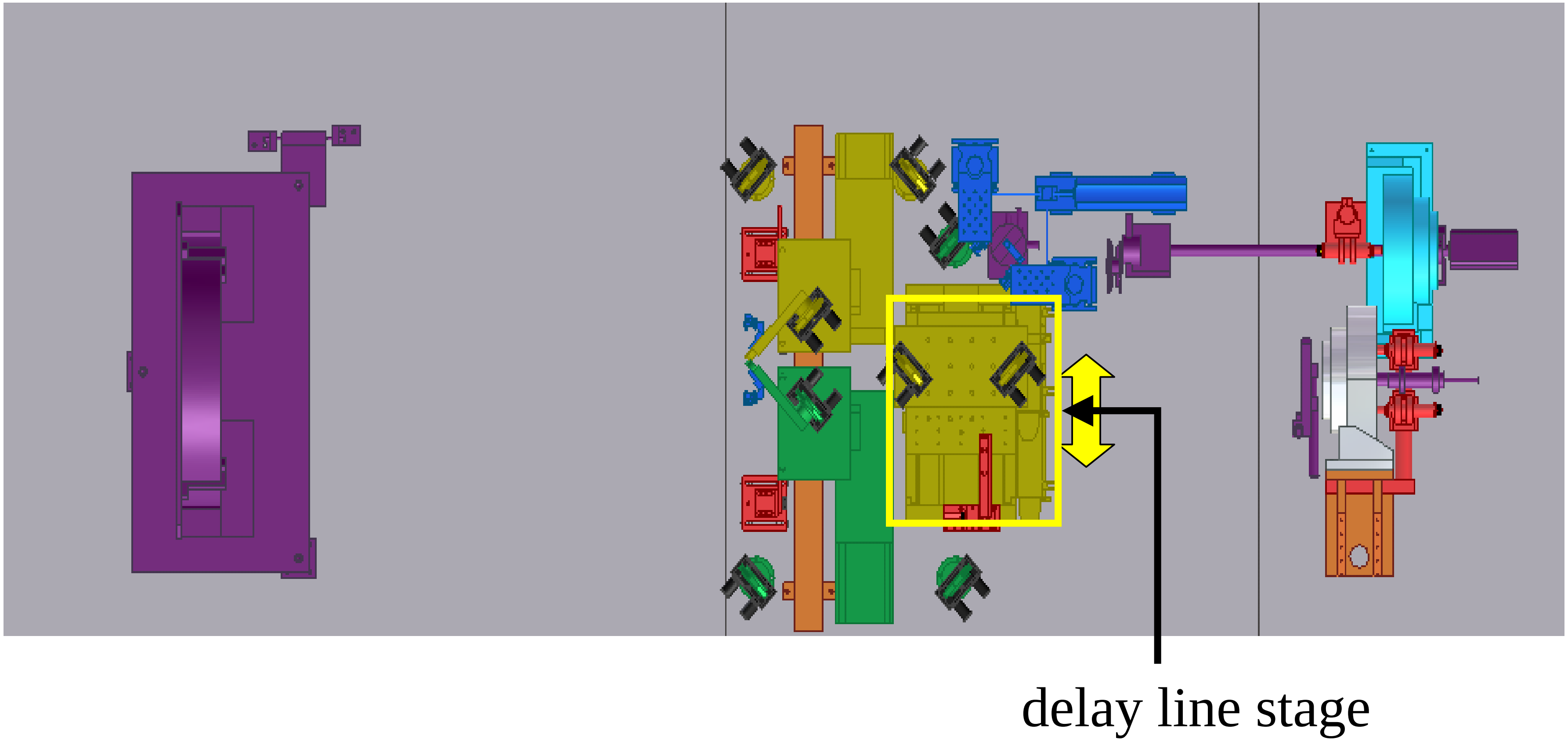

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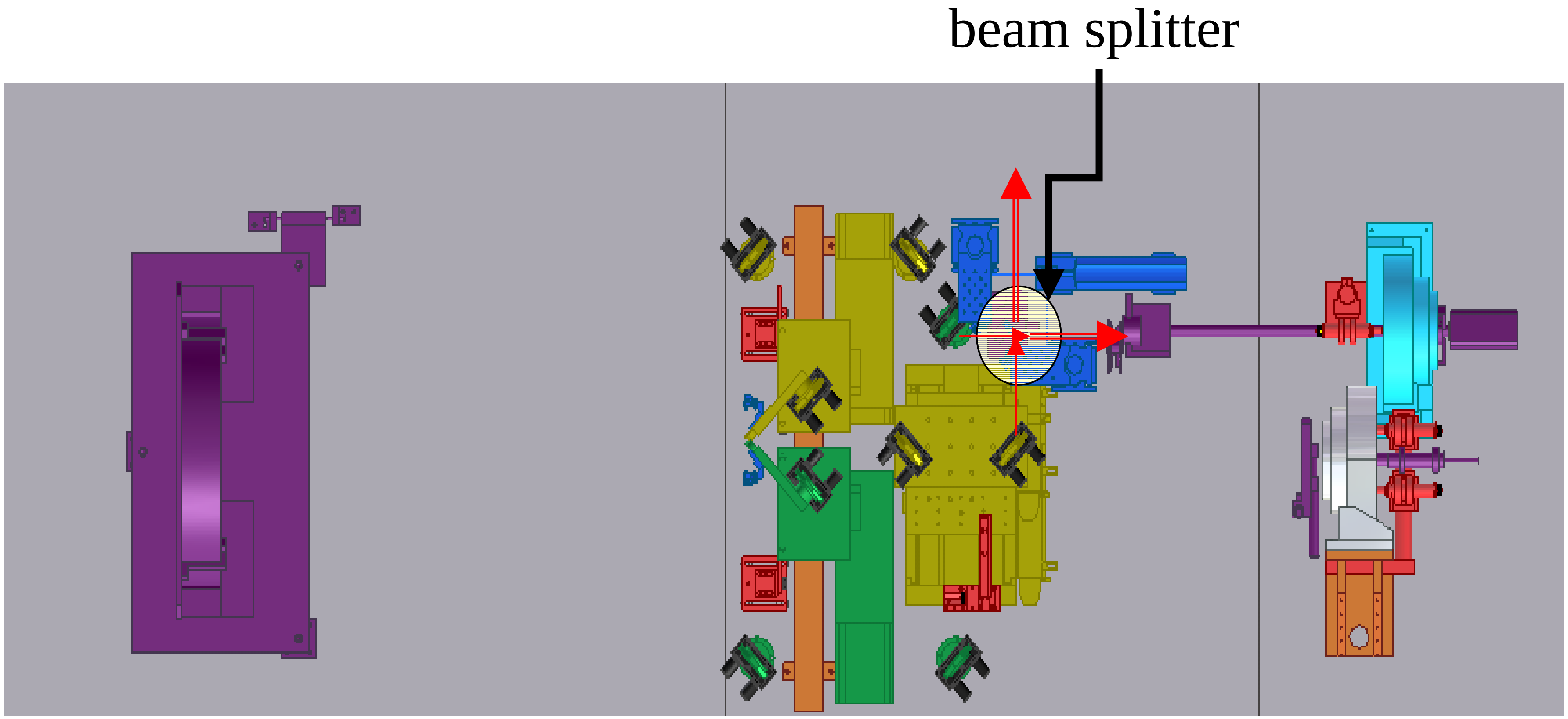
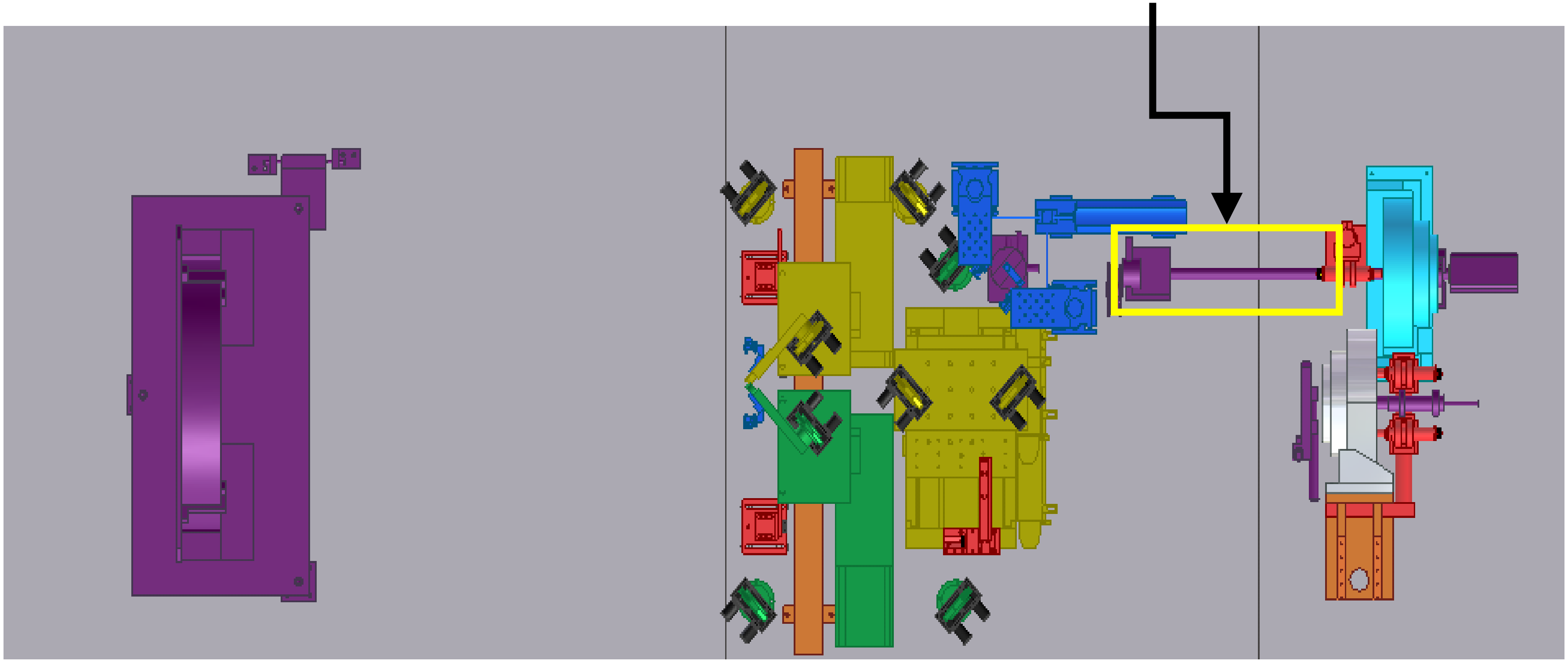


WIIT Schematic - Plan View

filter wheel, imaging lens & baffle



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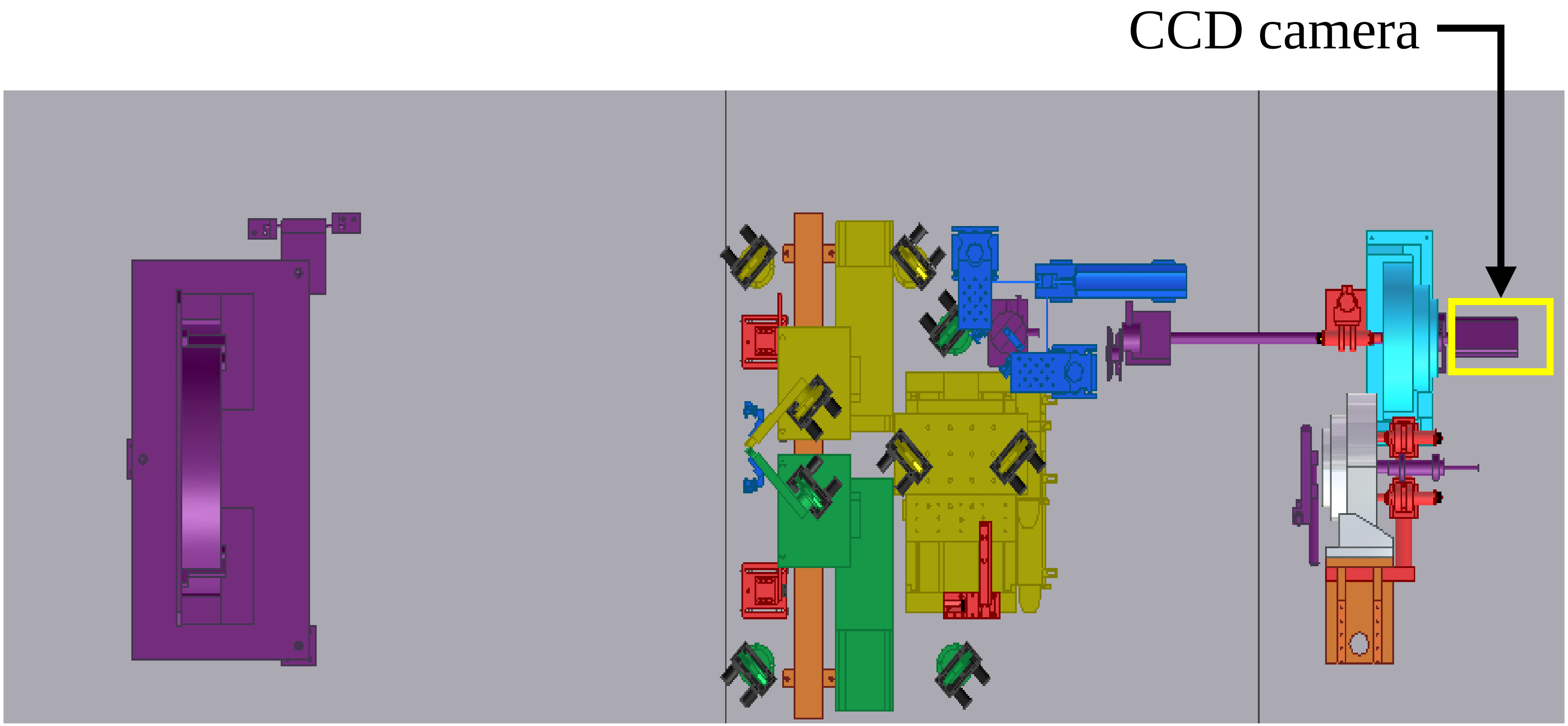

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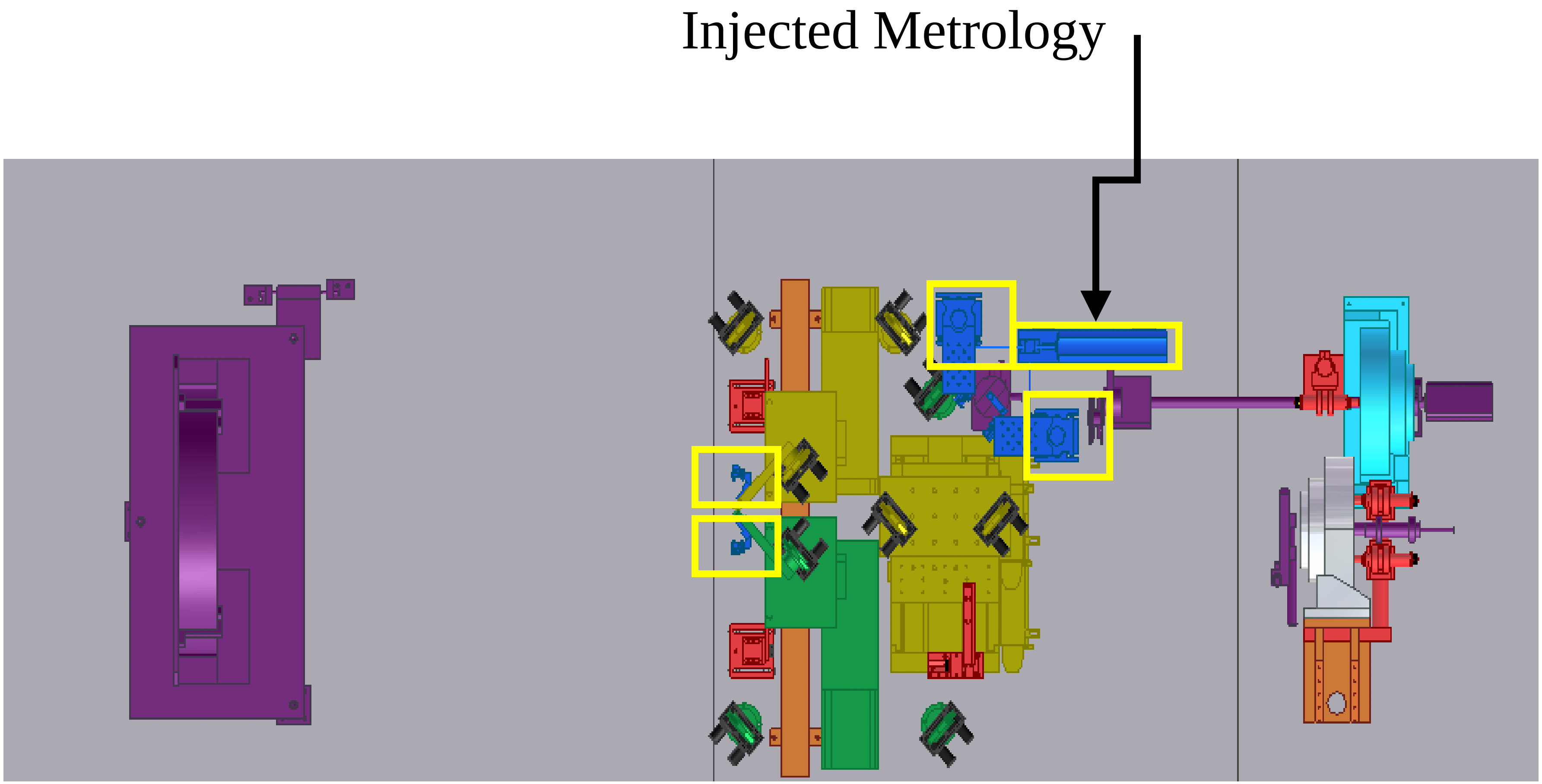
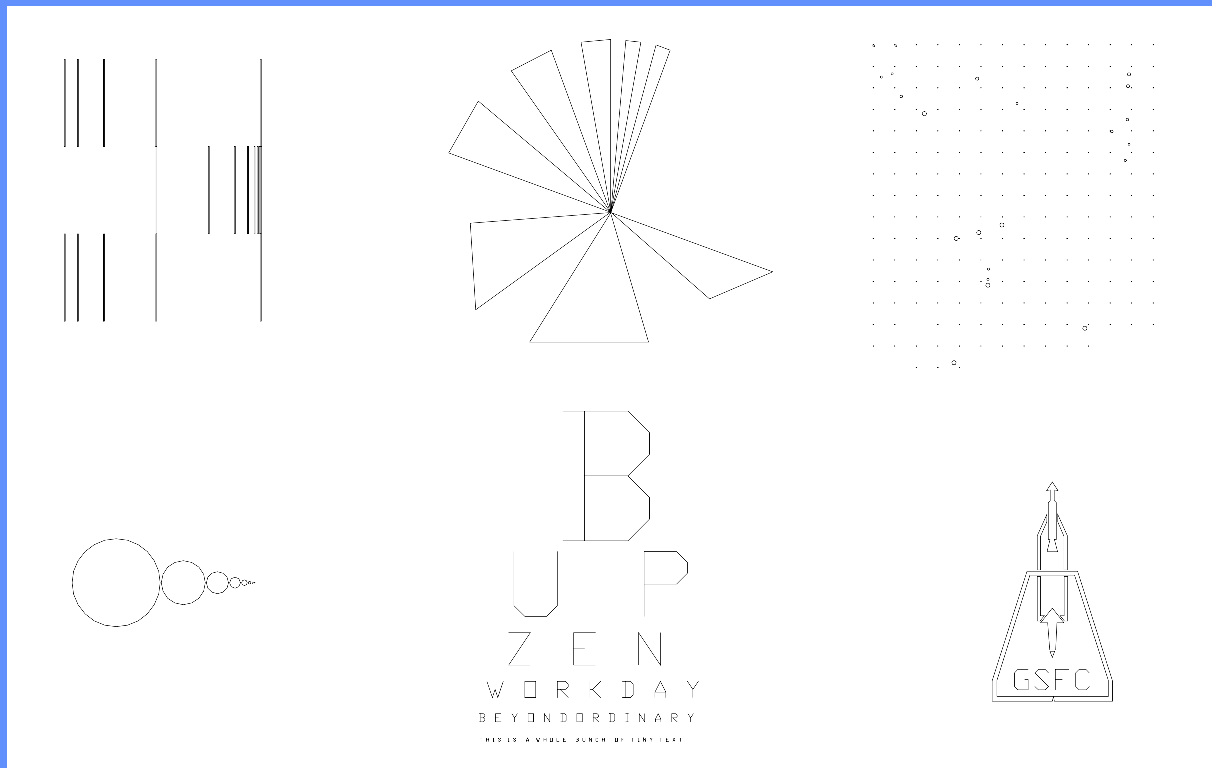
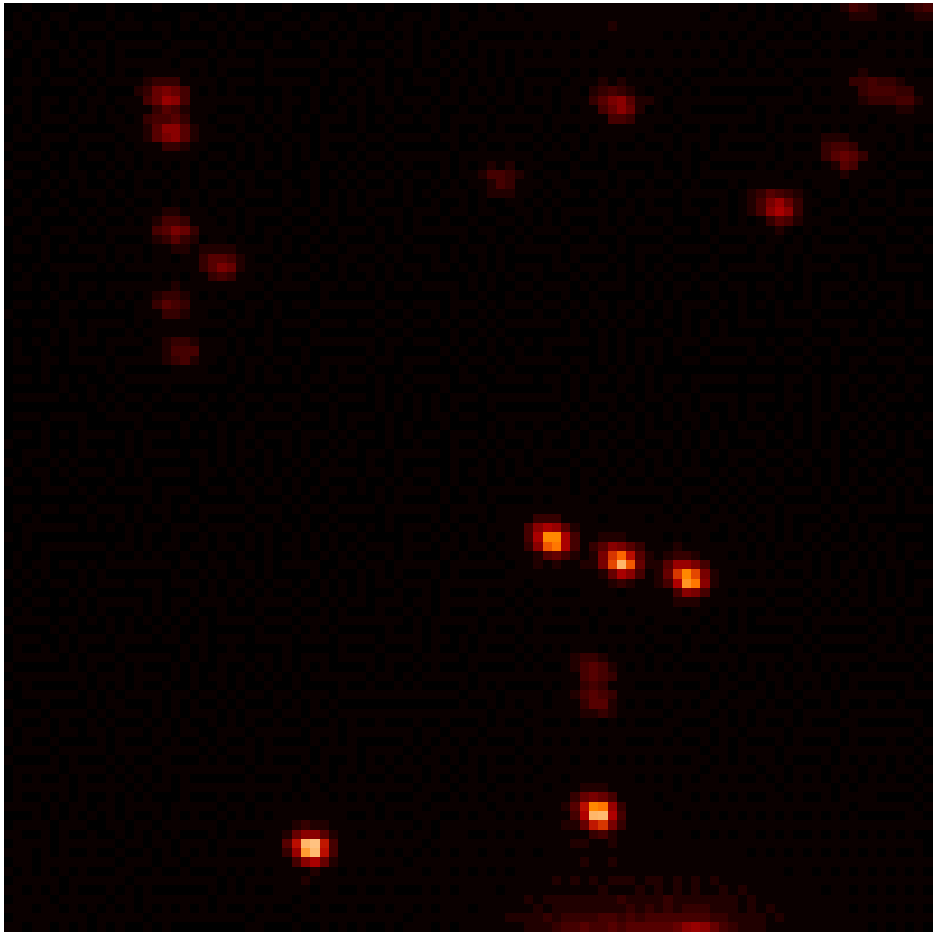


Test scenes



Test scenes will be observed with the WIIT to measure resolution limits in both 1and 2 dimensions, test mosaicing procedures, and measure the effect of cross-talk on synthesized image quality.

A Simple Demonstration of Wide-field Double Fourier Interferometry



White light sources separated by >>λ/d appear in different camera pixels. As the optical delay line is scanned, a flickering signal is seen in different pixels as the white light fringes from the corresponding sources approach the zero path difference point.

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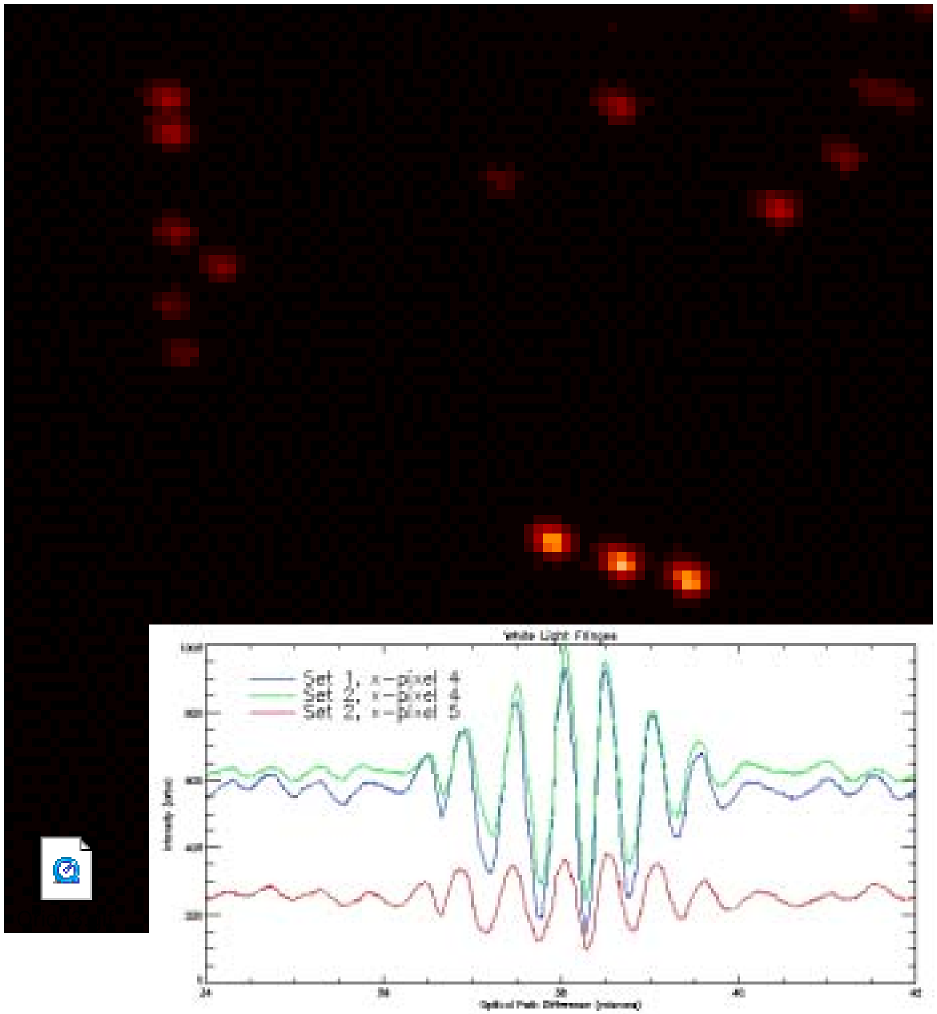

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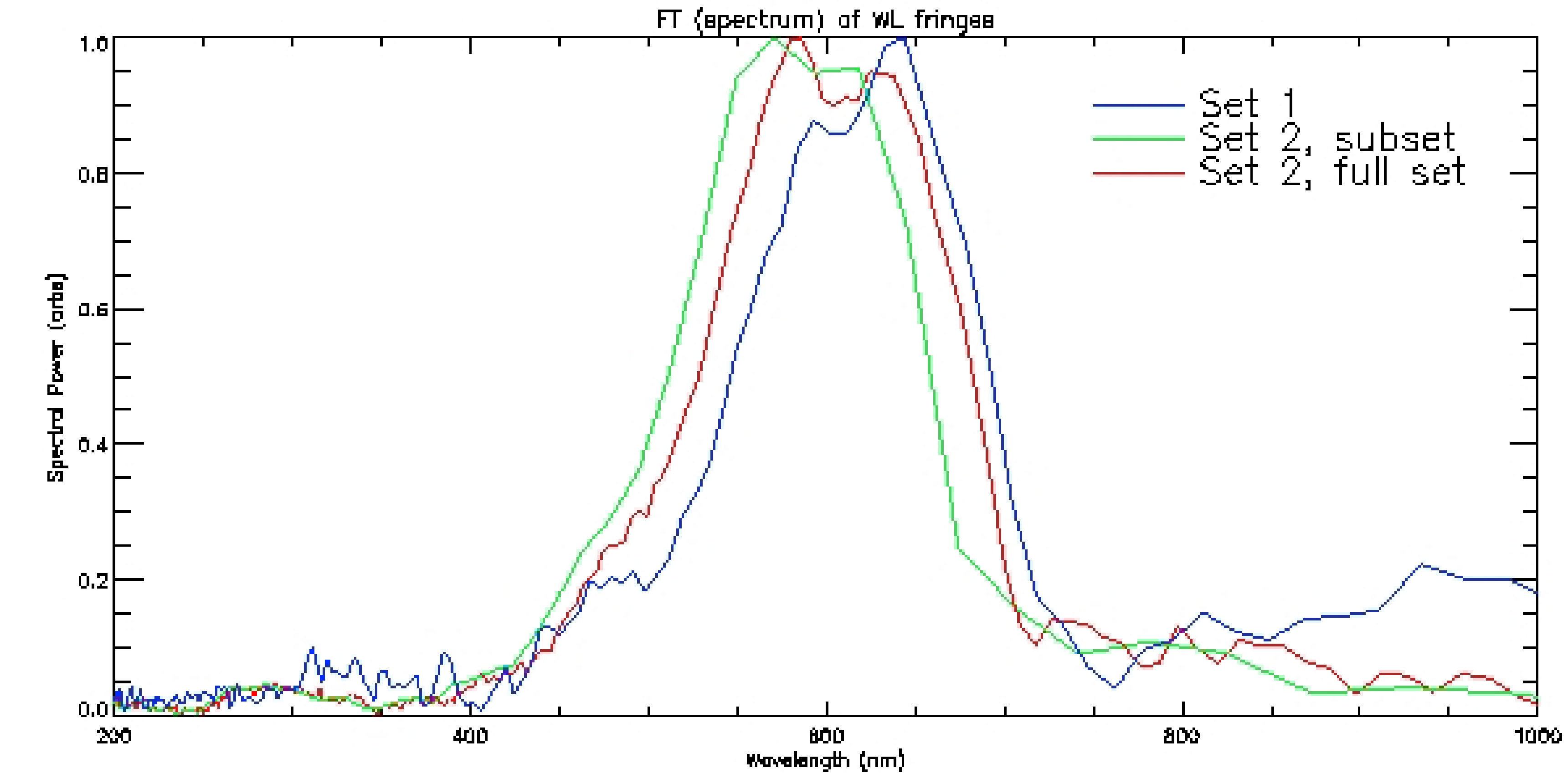
A different white light interferogram is recorded in each pixel

The Spectrum of Each Source is the Fourier Transform of its White Light Interferogram

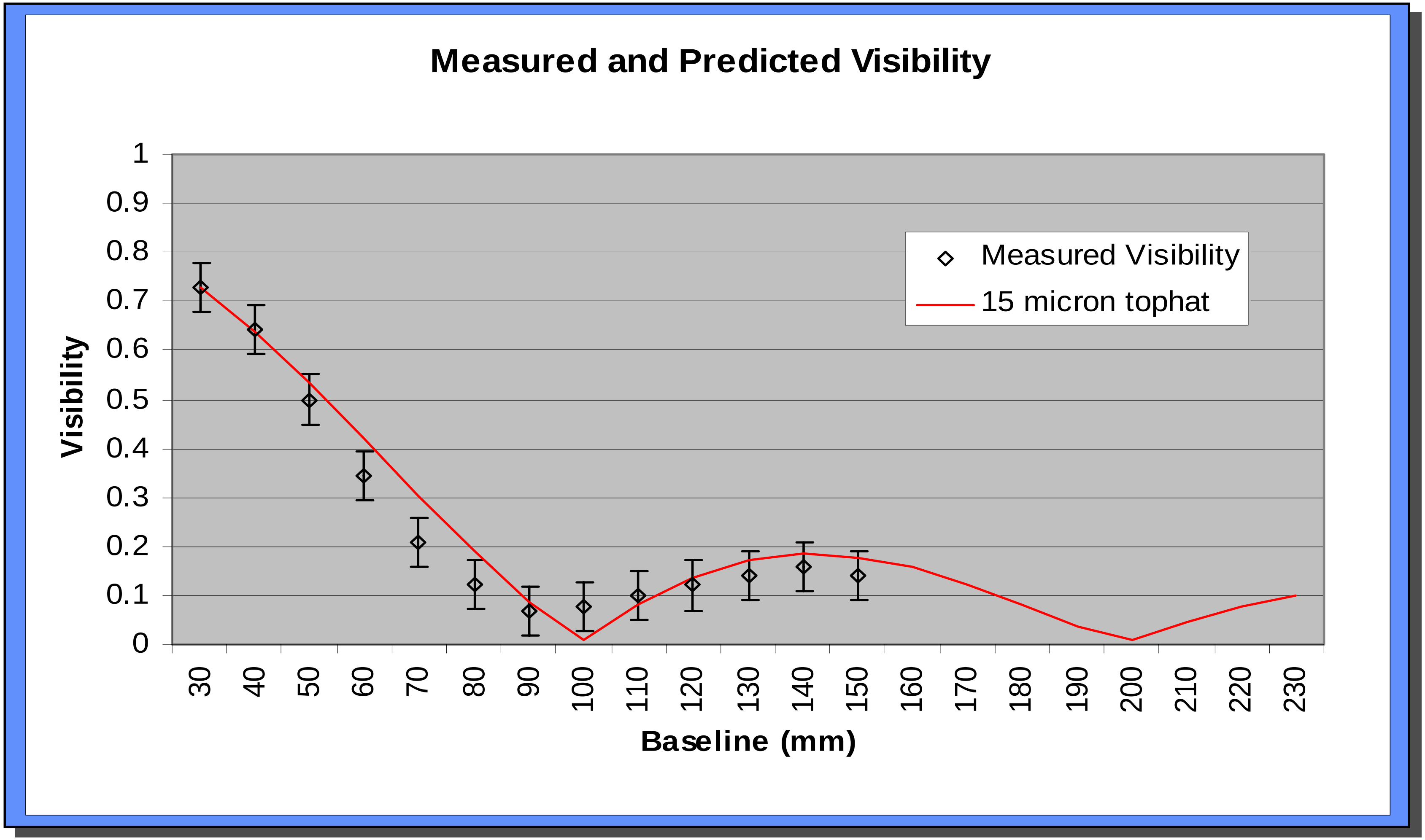


Spatial Interferometry (Imaging)

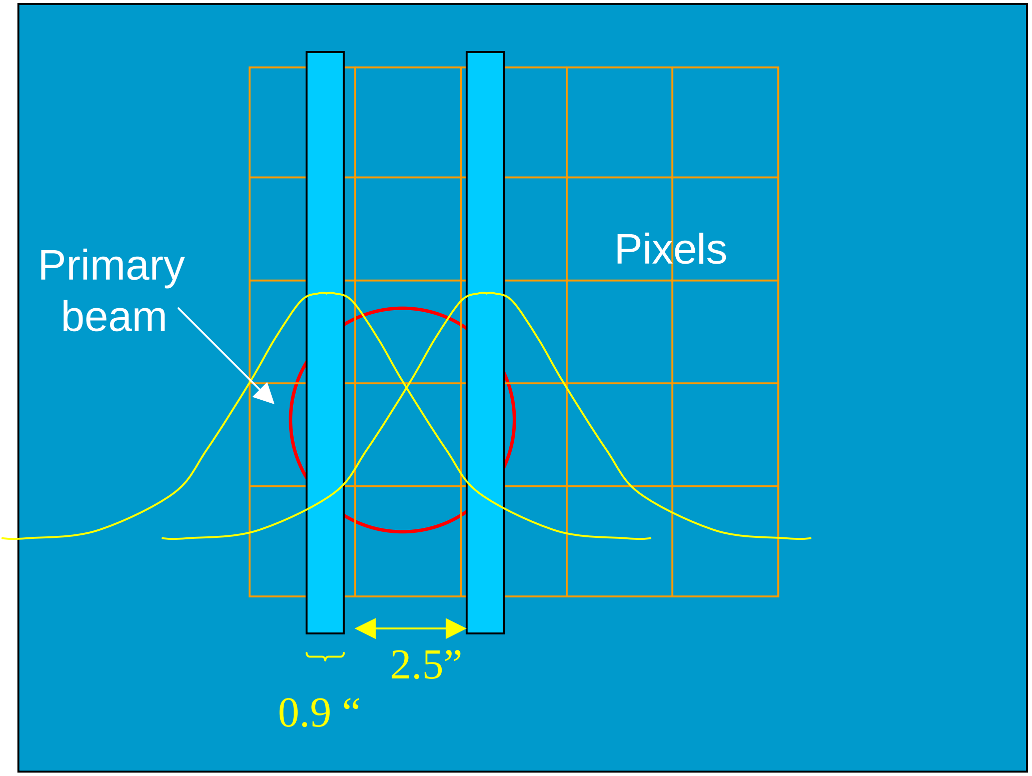
For a top-hat spatial brightness distribution of angular width α, the predicted visibility is

$$V = \sin(\pi b\alpha/\lambda) / (\pi b\alpha/\lambda) = \mathrm{sinc}(\pi b\alpha/\lambda)$$

where λ is wavelength and b is the baseline length.



Wide-field Imaging Interferometry Data



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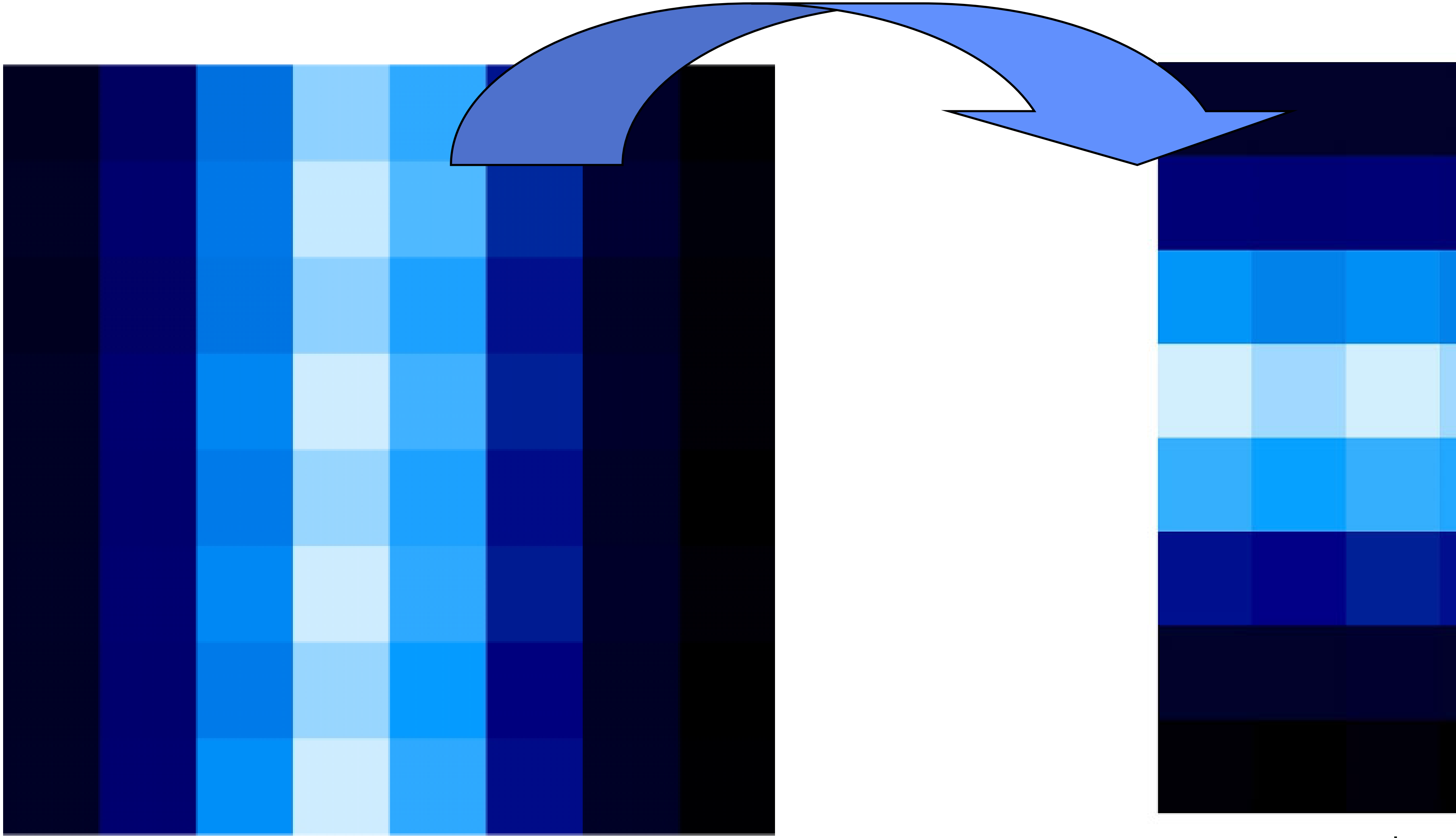

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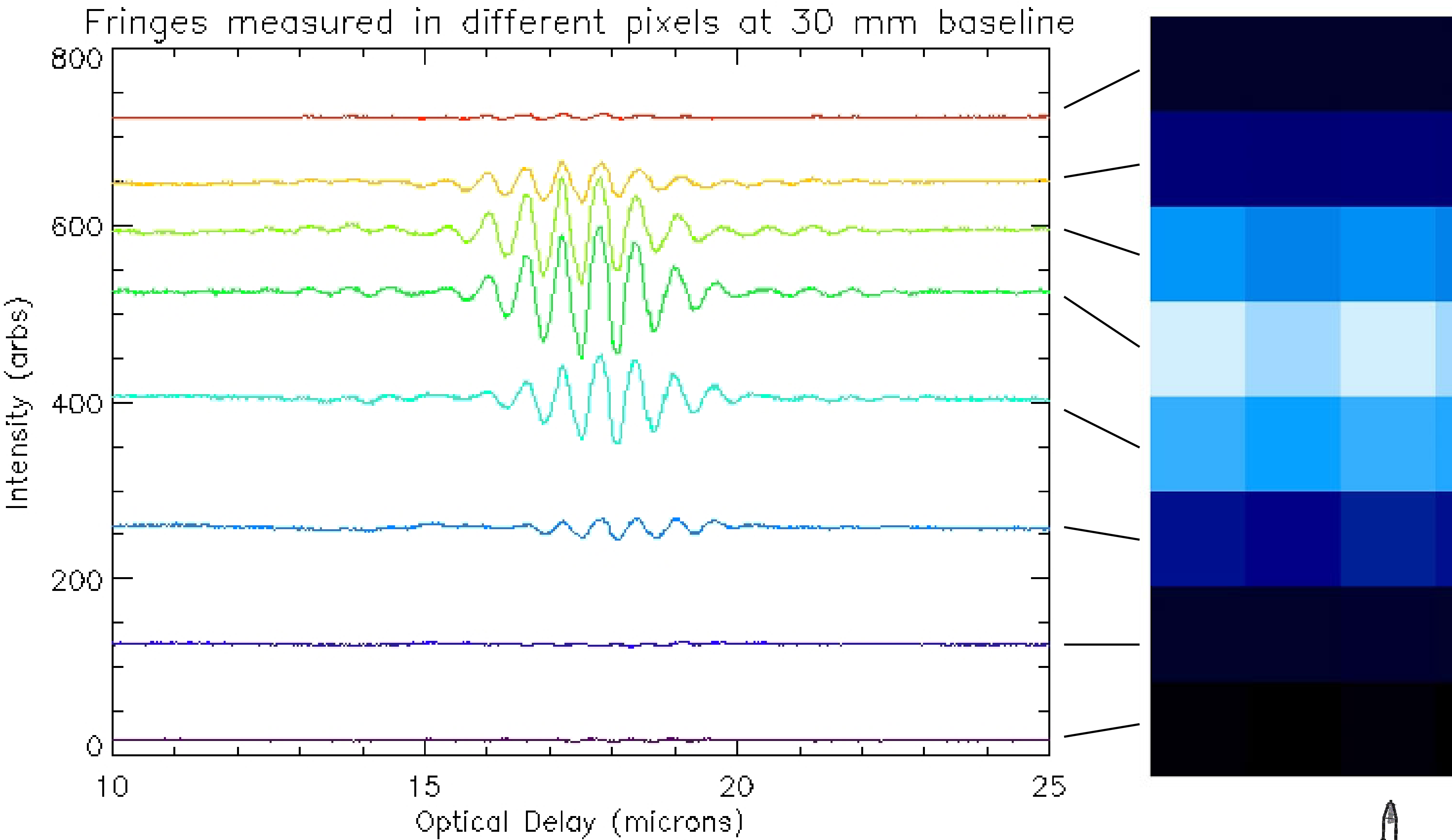

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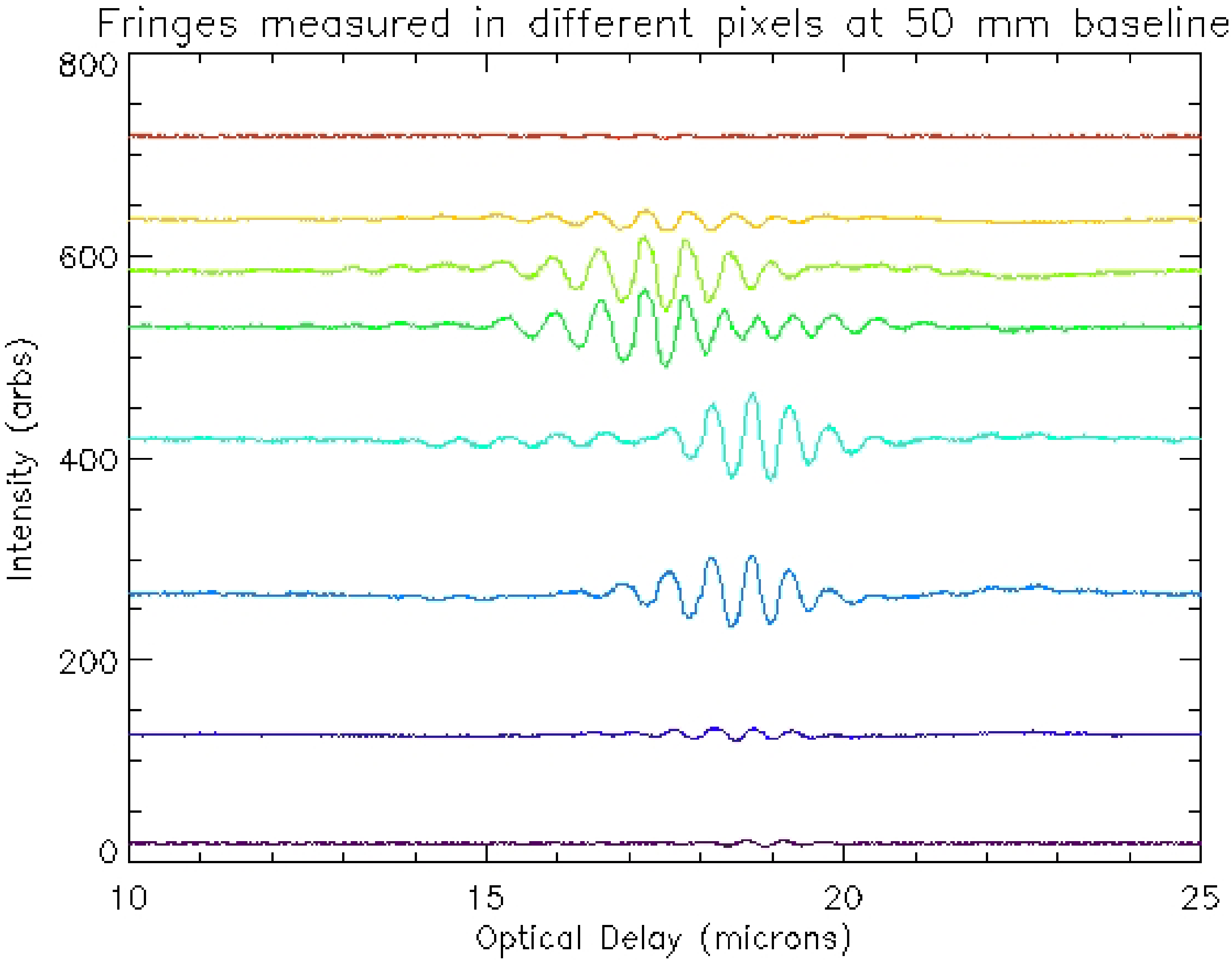
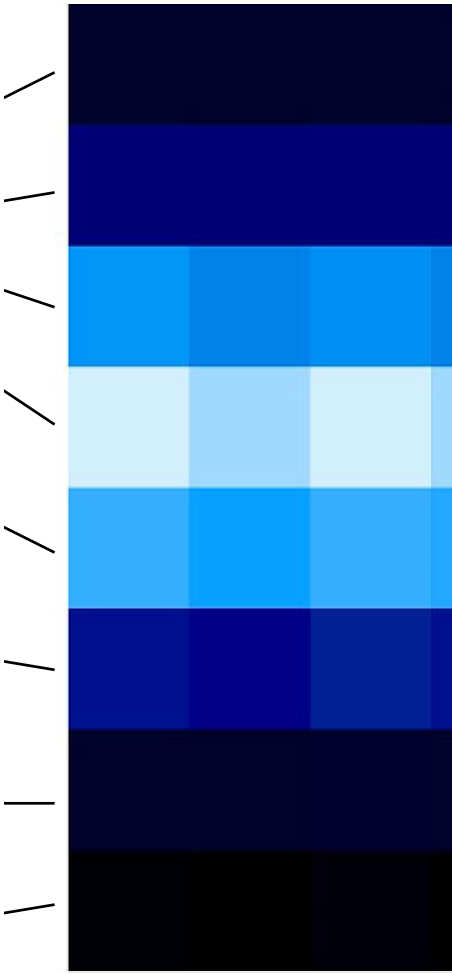




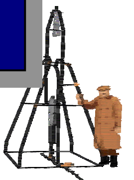
Algorithms

Some radio astronomy techniques can be adapted, but …

there are unique aspects to optical/IR interferometry (phase not measured at collector telescopes)

Possibilities:

1. Treat data as if they were produced by N_x x N_y separate Michelson interferometers: 1-D FT first to get spectrum, then 2-D FT to synthesize images, CLEAN, and splice together to create a 3-D wide-field mosaic.
2. Interpolate all the data onto an even *u-v* and wavenumber grid prior to discrete Fourier inversion into a wide-field spatial-spectral data cube
3. Same as (2), but use direct Fourier inversion (no regridding)
4. Iteratively fit a model brightness distribution, minimizing the difference between the expected response of the interferometer to this brightness distribution and the observed response, subject to constraints, and given the measurement uncertainties and correlations (i.e., data covariance matrix)



Summary

- Spatial-spectral (double Fourier) and wide-field imaging interferometry are naturally complementary techniques which can be used to enhance the measurement capabilities of TPF-I/Darwin for general astrophysics applications
- We built the Wide-field Imaging Interferometry Testbed (WIIT) to develop these techniques for the far-IR/submillimeter interferometers SPIRIT and SPECS
- On TPF-I/Darwin, a scanning delay line with an optical delay range of ~1 cm can be used to provide both R~1000 spectroscopy and, with the introduction of a 40^2 pixel detector array, a FOV of ~12 arcsec. Cryogenic delay lines comparable to the one that would be required already have flight heritage (e.g., Cassini CIRS, COBE FIRAS).
- Data from WIIT will be used to test algorithms for wide-field mosaic imaging

Acknowledgments

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